ON FIBERS RESEMBLING FUSED QUARTZ IN THEIR ELASTIC PROPERTIES.

By K. E. Guthe.

The advantages of quartz fibers as suspensions, principally their small elastic fatigue, great strength, and the possibility of drawing very fine threads, have led to their use in a great many important investigations where fine suspensions and a steady zero point are required.

In my work, suspensions were needed, able to carry a load of 500 grams and more and at the same time having as small an elastic fatigue as possible. Naturally fused quartz was selected as the substance promising the best results. Such fibers must be rather thick, from 0.1 to 0.2 mm in diameter. Since it was desired to draw them at least 1 meter in length, it required the melting of a rather large bead free from air bubbles. The process of building up quartz rods is known to be rather tedious. Shenstone's method[a] is simpler, and consists of heating the crystals to about 1,000° C. and suddenly quenching them in cold water. The crystals after such treatment are not shattered, and do not break when brought into the oxy-hydrogen flame. A stick of the proper dimensions is easily formed, containing, however, a large number of air bubbles. To remove these is a very tedious task and particularly exasperating, because quartz at the high temperature of the blowpipe flame is quite volatile, about one-half of the mass evaporating during the process.

Whichever method is employed it means a considerable loss of time, if a great many fibers of the dimensions necessary for this work have to be drawn.

Boys, in his first paper on this subject,[b] mentions his experiments on a great many minerals, of which only a few, however, could be drawn into fibers, and these he says were far inferior to those made from

[a] Shenstone: Nature, **64**, p. 65; 1901.
[b] Boys: Phil. Mag., **23**, p. 489; 1887.

fused quartz. I have also tried a great number of substances, all silicates of magnesium: Enstatite, Olivine, Serpentine, and Meerschaum, without success. Only the Amphibol-Asbestos, $Mg_3CaSi_4O_{12}$, in the ordinary mineral form, as well as when specially prepared for chemical purposes, and the Steatite or Soapstone, $Mg_3H_2Si_4O_{12}$, give clear beads before the oxy-hydrogen blowpipe. These, under proper precautions, can be drawn easily to fibers of the desired dimensions. The soapstone is especially easily worked and gives fibers of practically the same elastic properties as those of quartz. Since the method of making them is so simple and requires little time, a short description may be of general interest. The soapstone when heated to a high temperature becomes exceedingly hard, and is used commercially under the name of "lava" for making apparatus intended to be able to stand high temperatures—for example, tips of gas-burners. While it can not be melted before an ordinary blowpipe, it does so before an illuminating gas-oxygen jet and forms a clear bead, usually of a greenish tint, due to the presence of a trace of iron. The original soapstone or the "lava" will do equally well, the most convenient form being small cylindrical sticks. (I obtained such cylinders 3 mm in diameter and 7 cm long, giving colorless transparent beads about 5 mm in diameter, from the Chattanooga Sunlight Lava Manufacturing Company.) If the flame of the blowpipe is too long or the mixture of the gases not well adjusted, the substance will boil violently, while with a small, quiet flame it melts without boiling, a slight development of gases being noticeable only at the upper, cooler part of the bead. After taking the pearl out of the flame the thread is drawn, its thickness depending upon the temperature and rapidity with which it is drawn. Very fine fibers can thus be secured. The fibers should not be heated after being drawn. In a Bunsen burner, for instance, they will immediately become white and break to pieces.

Elastic fatigue.—It is very well known that fine quartz fibers show hardly any elastic fatigue,[a] but with thicker fibers of 0.1 to 0.2 mm diameter the effect of elastic fatigue became quite apparent. Careful experiments showed that small twists, or twists of small amplitude, do not affect the zero point, while larger twists, being continued for several minutes, would displace the zero point. The apparatus used allowed a turning of the torsion head, while the lower end of the fiber was held in its original position. After release the zero could be redetermined in a few seconds and the slow disappearance of the effect of elastic fatigue observed. With fibers 70 cm long and 0.1 mm diameter

[a] Boys: Phil. Mag., **23**, p. 496, 1887; Threlfall: Phil. Mag., **30**, p. 113; 1890.

the displacement, after release from a torsion of 360° lasting five minutes, amounted to as much as 2 in 3,000. Fibers made of steatite showed about the same effect, which is, however, very much smaller than any other substance experimented with, and about one-half to one-third of that shown by steel or phosphor bronze.

For these experiments the quartz and steatite fibers had been silvered at their ends, then coppered, and finally soldered into large brass pins clamped securely in the supports. Thus the elastic fatigue observed can not be attributed to an effect of the material with which fibers were fastened to the other parts of the instrument.

Tensile strength.—The tensile strength of very thin quartz fibers is quite large, 10×10^9 dynes per cm^2, but it decreases appreciably with increasing thickness.[a] My experiments show the same results. From the following table it is seen that the tensile strength of the steatite fibers is at least as large as that of quartz. For comparison the values given by Boys (B) are added. The decrease of tensile strength for the thicker fibers is very striking. For the thickest fibers it is, however, still as large as that of brass.

TABLE I.

Quartz.		Lava.	
Diameter.	Tensile strength.	Diameter	Tensile strength.
cm	$\frac{Dynes}{cm^2}$	*cm*	$\frac{Dynes}{cm^2}$
(B) 0.00048	11.5×10^9		
(B) .00175	8.0		
.0075	6.21	0.006	13×10^9
.0095	6.91	.0095	9.96
.010	6.16	.010	9.11
.015	4.5	.011	7.19
.0175	3.91	.0135	6.92
.018	4.08		

For thick rods the tensile strength is considerably smaller, as shown recently by Schulze,[b] who found a value of 0.6×10^9 dynes/cm^2 for a rod having a cross section of 0.272 cm^2.

[a] Boys: Phil. Mag., **30**, p. 116; 1890.
[b] Schulze: Ann. d. Phys., **14**, p. 384; 1904.

Coefficient of simple rigidity.—The torsional coefficient was determined by the well-known method of vibration. The diameter and length of the fibers were carefully measured, a cylinder made of Tobin bronze was suspended by the fibers, and the period of the torsional vibrations determined by means of a chronometer. Then

$$n=\frac{8\pi IL}{r^4T^2}$$

Since it became apparent that different fibers of the same substance gave slightly different values, and since I measured the diameter of the fibers only with an accurate micrometer, I did not take the trouble to correct for the coefficient of expansion.[a]

The mean of a number of experiments gave for quartz $n=3.4\times10^{11}$; for the steatite fiber a value from 2.6 to 4.2×10^{11}. Also in this respect the new fiber almost exactly equals fused quartz. The temperature coefficient of the torsional constant of quartz is given by Threlfall as +0.000133; by Barnett as +0.000115;[b] I obtained +0.000149. Steatite does not show the remarkable property of becoming more rigid at higher temperatures. Its temperature coefficient is negative, $\alpha=-0.000193$. The results obtained are given in Table II and plotted in fig. 1.

TABLE II.

Quartz.			Lava.		
Temperature.	Period.	n	Temperature.	Period.	n
°			°		
8.5	8.3083	3.4044×10^{11}	11.45	8.7507	3.9830×10^{11}
19.0	8.3020	3.4096	17.10	8.7556	3.9777
22.45	8.2997	3.4115	22.05	8.7590	3.9755
26.2	8.2973	3.4134	26.75	8.7625	3.9723

[a] See also Threlfall; loc. cit., p. 108.
[b] Barnett: Phys. Rev., 6, p. 119; 1898.

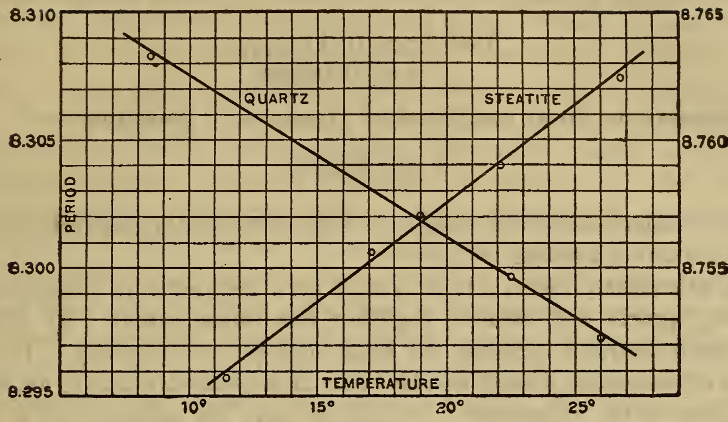

FIG. 1.

Coefficient of expansion of fused steatite.—The following experiments were made by Mr. L. G. Hoxton, of the Bureau of Standards, using a rather thick fiber of fused steatite.

The length between two fairly well defined marks 110.4 mm apart was compared at different temperatures with that of the standard nickel-steel decimeter No. 43, belonging to the Bureau and furnished with a certificate from the Bureau International des Poids et Mesures, which gives its linear coefficient as $\alpha=0.96\times10^{-6}$. In the following table the differences between the length of the fiber and the standard are marked F–NS. In the third column is given the linear coefficient of expansion, counting from the lowest temperature, and in the last the number of observations made for each temperature.

TABLE III.

Temperature.	F–NS.	α	Number.
°	μ		
+19.31	+10.3	0.000000317	5
+ 3.56	6.4	0.00000058	7
− 2.08	2.8	....	5
+21.8	12.4	0.000000365	4

The average relative coefficient is found from the normal equation

$$1059.4x = 410.1 \times \frac{1}{110400}$$
$$x = 0.00000350$$

The absolute linear coefficient of expansion is therefore

$$\alpha = 0.0000045.$$

The comparisons were made on a Zeiss horizontal comparator, which allows a direct reading of 1.0μ.

An attempt to obtain a fiber with a zero temperature coefficient by melting quartz and steatite together was unsuccessful. As soon as too much quartz is present the bead loses its transparency. If beads made of soapstone should not be clear, it is generally due to an excess of quartz in the substance. In such a case the addition of a small amount of magnesia or magnesium carbonate will clear up the bead.

Index of refraction of fused steatite.—Two small prisms were ground from steatite beads, and their index of refraction for sodium light determined by the method of minimum deviation. The instrument used was a spectrometer reading to half minutes. Table IV contains the results.

TABLE IV.

	Angle of prisms.	Minimum deviation.	μ
Prism 1.....	60° 3′	44° 1′	1.576
Prism 2.....	60° 4′	44° 17′	1.578

Also for these determinations I am indebted to Mr. L. G. Hoxton.

From the above comparison we conclude that we have found in fused steatite a substance which shows all the characteristic properties of fuzed quartz. The method of drawing fibers from it is very simple, and since the substance is easily secured (an old jet of a gas burner will furnish a large number of fibers), these fibers may, with advantage, be used where economy of time is an important question. One more advantage lies in the easy handling of the fiber. While thick quartz threads break easily when bent, those of steatite may be bent considerably more without breaking.

Barnett[a] working with fibers from 0.005 to 0.007 cm in diameter did not detect any time effect upon the period. But I found a distinct effect with either quartz or steatite fiber. The quartz fibers became

[a] Barnett: loc. cit., p. 116.

more rigid in course of time, a behavior resembling that of metals.[a] Professor Carhart and the writer[b] have found, however, a decrease of rigidity in the case of phosphor bronze. Continued vibrations, especially of very large amplitude, seem to have a distinct influence upon this "settling down" to a steady state, if such can be obtained.

Tests have been made concerning this time change in order to determine whether different specimens of quartz will differ in their behavior—mine contained quite a large amount of strontium—or whether the difficulties are to be attributed simply to the size of the fibers. Fibers were drawn from a stick of quartz glass (Heraeus). These show no time effect if the load is very small in comparison with the tensile strength, but the time effect becomes more and more pronounced the larger the load. After a fiber 0.02 cm in diameter had been vibrated for about a week with a load of 400 grams, the latter was removed and the fiber allowed to rest for a couple of days. It showed a partial return to the original state. It seems that the thickness of quartz fibers can not be increased beyond 0.002 or 0.005 cm without the loss of the desirable properties which make them so well adapted for very fine suspensions.

[a] Nichols and Franklin: Elements of Physics, I, p. 99.
[b] Carhart and Guthe: Phys. Rev., 9, p. 292; 1899.